Effect of pesticides on integrated mite management in Washington State

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ABSTRACT

The effect of pesticides used against codling moth, *Cydia pomonella* L., on integrated mite management was studied for three years in five or six commercial apple orchards in central Washington. Phytophagous and predatory mites were counted throughout the season in blocks ranging from 0.4-1.6 ha in size treated with four codling moth insecticides. In one year of the study (2006), five out of six orchards experienced elevated mite densities relative to the standard. In four orchards, novaluron caused a 3.0-16.9× increase in mite populations; acetamiprid caused a 2.6-3.4× increase, and thiacloprid caused a 1.7-13.8× increase. In the fifth orchard, the organophosphate standard had an extremely high mite population, in addition to all three experimental treatments. In 2005 and 2007, only one or two orchards had elevated mite levels in the novaluron, acetamiprid, and thiacloprid treatments. Additive effects of codling moth and thinning programs were evaluated in small plot research trials. Treatments with all three elements [1) codling moth insecticide; 2) calcium polysulfide; 3) carbaryl] produced the highest levels of spider mites. Three sulfur-containing products (calcium polysulfide, ammonium thiosulfate, and dry flowable sulfur) were evaluated for their effect on *Galandromus occidentalis* (Nesbitt) and apple rust mite, *Aculus schlechtendali* (Nalepa). All three materials caused suppressed *G. occidentalis* numbers. Calcium polysulfide caused the greatest reduction in apple rust mite numbers, ammonium thiosulfate the least reduction, with dry flowable sulfur intermediate between the two. Additive effects of codling moth materials, carbaryl, and sulfur-containing products may be causing increased mite levels in Washington orchards.

Key Words: spider mite, integrated mite control, apple, acetamiprid, thiacloprid, novaluron, carbaryl, calcium polysulfide, lime-sulfur, dry flowable sulfur, ammonium thiosulfate

INTRODUCTION

Spider mites are induced pests of pome fruits, generally occurring in orchards which have been disrupted by pesticides. In wild or abandoned trees, spider mites are usually maintained at low densities by predators (Glass and Lienk 1971, Croft 1983). However, in heavily sprayed systems such as commercial apple orchards, perturbations occur regularly based on the need to control direct pests. In Washington State, codling moth, *Cydia pomonella* L., is the key direct pest of apple, and control measures used against it determine the entire pest management program and structure the fauna of the agroecosystem.

The history of spider mite management in apple orchards is characterized by disruption of mite biological control following the introduction of new materials for codling moth control. DDT was introduced following WWII, and its use in tree fruits was accompanied by large scale mite out-

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breaks (Newcomer and Dean 1946, Baker 1952, Clancy and McAlister 1956). As a result of the disruption, acaricide resistance became widespread (Hoyt and Caltagirone 1971). DDT was replaced by organophosphate insecticides, including azinphosmethyl, which initially were toxic to both pest and predatory mites. Spider mites became resistant to the organophosphates, but it was not until the primary predator of spider mites, *Galandromus (=Typhlodromus = Metaseiulus) occidentalis* (Nesbitt) also became resistant that the opportunity for integrated mite control arose in the western US (Hoyt 1969). Integrated mite management was then implemented on approximately 90% of the acreage (Whalon and Croft 1984) by conserving the organophosphate-resistant predatory mites, with growers actively avoiding materials that were toxic to these valuable predators. This opportunity, however, was predicated on continuing efficacy of azinphosmethyl for codling moth control.

The integrated mite control program implemented in the early 1970s in Washington remained largely effective through the 1990s. During this time shifts in the pesticide program occurred, at least for pests other than codling moth. The efficacy of the organophosphates against many of the secondary pests of tree fruit (aphids, leafhoppers, leafminers, and leafrollers) declined steadily through this period, and new materials were substituted for their control. The use of carbaryl for fruit thinning was implemented in the late 1970s; this carbamate insecticide was initially highly toxic to *G. occidentalis*, and its use was restricted to protect predator populations in integrated control programs. However, moderate levels of resistance to this carbamate were documented within a short period of use (Babcock and Tanigoshi 1988). Other carbamate insecticides, similarly toxic to the predator, were also used sparingly, typically only when no other substitute was available. The use of pyrethroids, notoriously disruptive to integrated mite control, was largely avoided in Washington apples in order to protect the integrated mite control program.

However, following almost forty years of reliance on azinphosmethyl for codling moth control, shifts in the codling moth management program began in the mid-1990s. These changes have been driven mainly by either the development of organophosphate resistance in codling moth or by regulatory issues (Beers *et al.* 2005). In the meantime, new control techniques and materials have increased in use. Mating disruption now forms the foundation of codling moth control in about 80% of Washington's apple orchards (J. Brunner, personal communication). Choices for supplementary insecticides include insect growth regulators and neonicotinoids. While the new materials meet the new standard for improved worker safety, their effects on natural enemies and predator/prey dynamics have not been well explored.

One class of alternative insecticide chemistry, the neonicotinoids, demonstrated a tendency to disrupt integrated mite control even in the early phases of testing (Beers *et al.* 2005). These tests, however, were characterized by small plots, high rates, and season-long programs. It remained to be seen if the potential for disruption still existed under commercial use conditions (large acreages, applications against a single generation of codling moth with any given material). Additionally, potential multiple-year effects from continued use of the same products could not easily be examined prior to registration.

Other shifts in the Washington pesticide program occurred during the same period as the change in the codling moth program, especially in the crop load regulation and fungicide programs. The blossom thinner, sodium dinitro-o-cresylate (Elgetol®), was withdrawn from the market in the mid 1990s, and its use was later replaced with calcium polysulfide (lime sulfur). A plant nutrient, ammonium thiosulfate, also became more widely used; its sulfur content is similar to calcium polysulfide. The use of sulfur fungicides increased in part because of the plantings of mildew-susceptible cultivars, and in part as an alternative mode of action for fungicide resistance management (FRAC 2008).

The goals of this study were to explore the effects on integrated mite control of three newer codling moth insecticides when used in a commercial setting; to examine the additive effects of codling moth insecticides, carbaryl, and calcium polysulfide in a seasonal program; and the comparative effects of three sulfur-containing compounds used as a blossom thinner, fungicide, and plant nutrient, respectively.

MATERIALS AND METHODS

Large-block experiment. This test was conducted in five (2005, 2007) or six (2006) commercial apple orchards from Bridgeport to Royal City, WA. Plot size ranged from 0.4-1.6 ha per treatment at each orchard; treatments were randomly assigned to one of four plots within an orchard, and replicated across the orchards. All treatments were applied at a finished spray volume of 935 litres/ha by the orchard's personnel using their own equipment. The dominant cultivar in the blocks was either 'Delicious' or 'Fuji'. Four of the orchards received the same treatments for all three years of the study (orchards ARR, BAN, QLR, SLH); MZN was treated in 2006-07, while RYL and BTE were treated only in 2005 and 2006, respectively.

Treatments consisted of one of the four insecticides used for codling moth control: acetamiprid, a neonicotinoid (Assail® 70W, Cerexagri, King of Prussia, PA; 0.17 kg AI/ha); thiacloprid, also a neonicotinoid (Calpyso® 4F, Bayer CropScience, Research Triangle Park, NC; 0.21 kg AI/ha); novaluron, a benzoylurea insect growth regulator (Rimon® 0.83EC, Chemtura, Middlebury, CT; 0.23 g AI/ha); and an organophosphate standard. For the organophosphate standard, growers could choose either phosmet (Imidan® 70W, Gowan, Yuma AZ; 3.9 kg AI/ha) or azinphosmethyl (Guthion® 50W, Bayer CropScience, Research Triangle Park, NC; 1.1 kg AI/ha). Applications of acetamiprid, thiacloprid, and novaluron were made only during the first generation of codling moth (May and June). Two applications of acetamiprid and thiacloprid were made per season, the first timed for 250 codling moth degree days, and the second 21 d later. Three applications of novaluron were made (based on its ovicidal activity), the first at petal fall, the second 14 d later, and the third 28 d later.

For the above the treatments, codling moth control for the second generation (July and August) consisted of two applications of the benzoyl hydrazine insect growth regulator methoxyfenozide (Intrepid® 2F, Dow AgroSciences, Indianapolis, IN; 0.28 kg AI/ha), the first timed for 1,250 codling moth degree days, and the second 21 d later.

In the organophosphate standard treatment, two applications were made per generation, using the same timing as for acetamiprid and methoxyfenozide for the first and second generations, respectively.

Mites were sampled every 2-3 wk from late May through mid-September. One hundred leaves per plot were collected from the center portion of the plot and kept cool during transportation and storage. The mites were brushed from the leaves using a mite brushing machine (Leedom, Mi-Wuk Village, CA) and collected on a revolving sticky glass plate. The composite sample on the plate was counted using a stereoscopic microscope. Phytophagous and predatory mites were recorded, including the motile stages of European red mite, *Panonychus ulmi* (Koch); twospotted spider mite, *Tetranychus urticae* Koch; McDaniel spider mite, *Tetranychus mcdanieli* McGregor western predatory mite, *G. occidentalis*; a stigmaeid predatory mite, *Zetzellia mali* Ewing, and apple rust mite, *Aculus schlechtendali* (Nalepa).

Additive effects experiment. This small-plot experiment examined the effect of adding one or two potentially disruptive compounds used for crop load regulation to the same codling moth programs (rates, timing, and materials) described for the large plot experiment. The compounds used were a blossom thinner, calcium polysulfide (Rex Lime Sulfur®, Or-Cal, Junction City, Oregon), and a fruit thinner, carbaryl (Sevin® 4F, Bayer CropScience, Research Triangle Park, NC). Both compounds were used at their respective recommended timings (Smith *et al.* 2006). Calcium polysulfide was applied three times (pink, 20% and 80% bloom) at a rate of 8% vol:vol. Carbaryl was applied twice, when the fruitlets were 8 and 12 mm in diameter, at rate of 1.7 kg AI/ha.

This test was conducted in a 2 ha block of mature 'Oregon Spur' and 'Red Spur' Delicious apples with 'Golden Delicious' pollenizers. Plots were five rows by five trees. The experimental design was a randomized complete block design with 12 treatments and 4 replicates. All applications were made with an airblast sprayer (Rears Pak-Blast, Eugene, OR) calibrated to deliver 935 litres/ha. Treatment timings and materials for first and second generation codling moth control were the same as described in the large-block experiment.

Mites were sampled every other week from May through September by collecting 40 leaves per plot. The leaves were collected, stored and processed as described above.

Sulfur products experiment. The second small-plot experiment examined the effect of three sulfur-containing products on *G. occidentalis* and apple rust mite. For purposes of comparison, the materials were applied to an existing population of these two species in June, rather than at their normal timing which ranged from prebloom through the early post-bloom period. The three sulfur products were calcium polysulfide (Rex Lime Sulfur®, Or-Cal, Junction City, Oregon; 12% vol:vol), ammonium thiosulfate (a plant nutrient) (Thio-Sul®, Tessenderlo Kerley, Phoenix, AZ; 3.4% vol:vol), and dry flowable sulfur (a fungicide) (Kumulus® 80DF, Micro-Flo, Memphis, TN; 10.8 kg AI/ha).

The experimental design was a randomized complete block (randomized on the basis of a pretreatment count) with seven treatments and four replicates. Each replicate consisted of three trees in a single row, with one untreated buffer row separating the treatment rows. Plots consisted of three cultivars, 'Oregon Spur', 'Goldspur', with 'Red Fuji BC2' in the center; however, only the center tree was sampled. Treatments consisted of either one or three applications of each of the three sulfur-containing compounds plus an untreated check. Treatments receiving a single application were applied 26 June 2006; treatments receiving three applications were made 26 June, 8 July and 19 July. Treatments were applied by airblast sprayer at 935 litres/ha. Mite populations were assessed by collecting 25 leaves per plot and processed using the method described above. Counts were made pretreatment and weekly after treatment through late July.

Data analysis. Cumulative mite days (CMDs) were calculated for tetranychid (*P. ulmi* plus *T. urticae*), predatory (*G. occidentalis* plus *Z. mali*), and apple rust mite. CMDs provide an estimate of population densities integrated over the course of the test, and are calculated as the sums of the average density of mites on two dates multiplied by the number of intervening days:

$$\text{CMD} = \Sigma 0.5(P_a+P_b)D_{a\text{-}b}$$

where P_a and P_b are the population densities (mean mites/leaf) at times a and b, and $D_{a\text{-}b}$ is the number of days between time a and time b.

Data were analyzed using the Statistical Analysis System (SAS 1988). Data were tested prior to analysis for homogeneity of variance using Levene's (1960) test. Variances found to be non-homogeneous were transformed [ln(y+0.5)] before analysis. PROC GLM was used to conduct an analysis of variance, and treatment means were separated using the Waller-Duncan *k*-ratio *t*-test. Single degree-of-freedom contrasts were used to compare groups of treatments in the small plot experiments.

RESULTS

Large-block experiment. Spider mite populations in the experimental blocks consisted primarily of European red mite, with 99, 92, and 78% of the population of motile forms comprised of this species in 2005, 2006, and 2007, respectively. Twospotted spider mite was the next most numerous species; a relatively higher proportion of this species occurred only in one orchard, MZN, in 2007, when 57% of the motile forms were twospotted spider mite. Only trace numbers of McDaniel spider mite were found during the course of the study.

There were no statistical differences among treatment mean CMDs for tetranychids or for predatory mites in any of the three years of the study (Table 1). In 2005 and 2006, rust mite populations were higher in the acetamiprid treatment compared to the standard. In general, the differences in densities among years and orchards were greater than those among treatments.

Despite this variation, some trends in these data are apparent. In 2005, elevated mite densities occurred in only one of five orchards (QLR) (Fig. 1). However, the highest mite levels occurred in the novaluron (peak density 54 mites/leaf), acetamiprid (21 mites/leaf), and thiacloprid (20 mites/leaf) treatments, with only a moderate increase in the organophosphate standard treatment (11 mites/leaf). Not all of the population peaks in the treatments with newer insecticides can be explained by low predator numbers, although predatory mite densities were highest in the organophosphate treatment (peak density 2.3 predators/leaf). The thiacloprid treatment peaked at 0.9 predators/leaf, while the acetamiprid and novaluron treatments never exceeded predator densities of 0.3/leaf. Apple rust mite densities were moderate in most of the treatment (peak density of 150-300 rust mites/leaf), with the exception of the novaluron treatment, which had relatively low rust mite densities (<10/leaf) for most the season.

Mite densities were much higher overall in 2006 than in 2005 (Fig. 1). Five of six orchards experienced elevated tetranychid mite densities in one or more treatments. This may have been due to a cumulative effect of disruptive products in four of the orchards; however, 2006 was characterized by a high frequency of mite outbreaks throughout the central fruit-growing district of the state. The novaluron treatment had elevated tetranychid mite levels in five orchards (20-45 mites/leaf at peak density); the acetamiprid treatment in two orchards (22-34 mites/leaf); and the thiacloprid treatment in three orchards (13-32 mites/leaf). One orchard (QLR) had a high peak mite density in the organophosphate treatment, as well as the other three treatments; however, this was the same orchard that had high levels in several treatments the previous year. Trends in predatory mite densities were again difficult to interpret. Although no statistical differences occurred among treatment means for the entire season, the peak densities of predators occurred too late in the season to prevent the mid-July peak in tetranychid mites (data not shown).

Mite densities in the experimental orchards were much lower in 2007 than in 2006 (Fig. 1), with no treatment exceeding 7 mites/leaf. Only two of the five orchards experienced a moderate increase in tetranychid mite levels, with a slight elevation in the novaluron treatment in one orchard (SLH) (6.2 mites/leaf peak density), and acetamiprid in two orchards (4.4 and 3.5 mites/leaf in MZN and SLH, respectively) and thiacloprid (3.6 mites/leaf) in one orchard (MZN).

Additive effects experiment. The results from the experiment examining the additive effect of several disruptive products during the season showed a distinct trend toward increased tetranychid mite densities when one of the newer codling moth insecticides was used in the same program with both a blossom and fruit thinner (Fig. 2). The lowest tetranychid mite densities occurred in those treatments where only insecticides for codling moth were used. Treatments where all three compounds were used (codling moth insecticide

Table 1.
Seasonal mite densities (cumulative mite days) resulting from four codling moth control regimes, in commercial apple orchards in Washington, 2005-2007

Treatment	Rate (AI/ha)	n	Cumulative mite days[1] Tetranychids (± SEM)	Predators (± SEM)	Apple rust mite (± SEM)
			2005		
Acetamiprid	0.17 kg	5	113 ± 99a	12 ± 2a	10,861 ± 2,690a
Thiacloprid	0.21 kg	5	93 ± 84a	17 ± 4a	8,563 ± 1,718ab
Novaluron	0.23 kg	5	252 ± 244a	11 ± 3a	6,589 ± 2,639b
Standard	---	5	49 ± 38a	26 ± 8a	6,668 ± 1,394b
		F, P	4.32, 0.013	1.90, 0.16	12.03, 0.0001
			2006		
Acetamiprid	0.17 kg	6	267 ± 132a	26 ± 3a	870 ± 372a
Thiacloprid	0.21 kg	6	305 ± 149a	28 ± 5a	634 ± 244ab
Novaluron	0.23 kg	6	520 ± 178a	33 ± 13a	563 ± 301ab
Standard	---	6	401 ± 343a	27 ± 5a	476 ± 197b
		F, P	4.78, 0.0045	1.98, 0.12	19.80, <0.0001
			2007		
Acetamiprid	0.17 kg	5	55 ± 31a	29 ± 13a	719 ± 346a
Thiacloprid	0.21 kg	5	18 ± 10a	35 ± 14a	883 ± 240a
Novaluron	0.23 kg	5	37 ± 23a	16 ± 8a	346 ± 153a
Standard	---	5	23 ± 15a	32 ± 16a	632 ± 229a
		F, P	6.17, 0.0032	5.74, 0.0043	3.43, 0.030

[1] Means within columns not followed by the same letter are significantly different. For 2005 and 2007, df=7, 19; for 2006, df=8, 23.

+ calcium polysulfide + carbaryl) had significantly higher tetranychid mite densities than when codling moth insecticides alone were used (df=1, *F*=5.54, *P*=0.02).

Trends in seasonal densities of predatory mites and apple rust mite were less clear (Figs. 3, 4). Comparisons of treatments with or without calcium polysulfide indicated that there was a significant reduction in the seasonal apple rust mite densities where calcium polysulfide was included in the program (df=1, *F*=5.07, *P*=0.03), however, there was no effect on predatory mite densities (df=1, *F*=0.70, *P*=0.41).

Sulfur products experiment. All three sulfur products used in this study suppressed *G. occidentalis* to about the same extent (Fig. 5). There was a 64-74% reduction in densities of *G. occidentalis* in the treatments containing sulfur products in relation to the check. There was no difference between treatments with one application versus three applications (df=1, *F*=0.11, *P*=0.75), likely because most of the mortality had occurred from the first application, without sufficient time for reinfestation between applications.

The effect of the three sulfur products on apple rust mite was more variable. There was a 30-80% reduction in densities of apple rust mite in these treatments. The reduction in apple rust mite numbers was greatest in the calcium polysulfide treatment (Fig. 6), and least in the ammonium thiosulfate treatment. As with *G. occidentalis*, there were no differences in treatment means between treatments with one versus three applications (df=1, *F*=0.99, *P*=0.33).

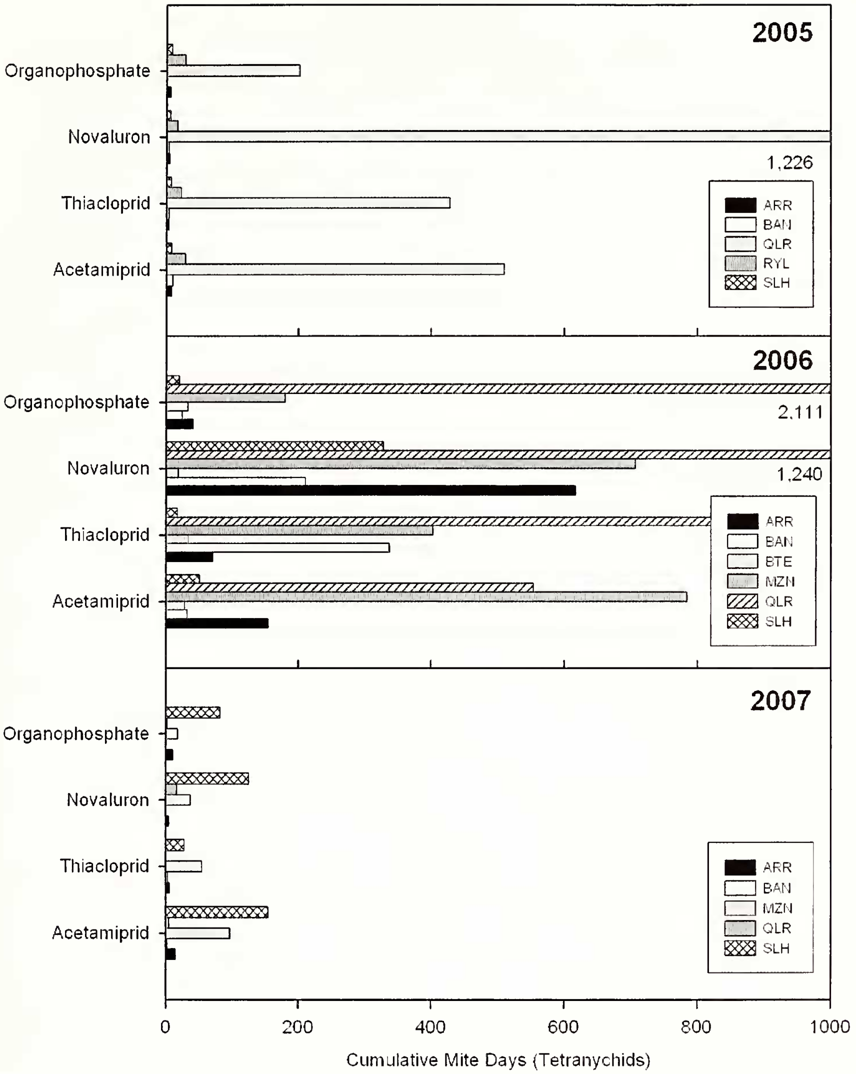

Figure 1. Seasonal tetranychid mite densities (cumulative mite days) in commercial apple orchard blocks treated with four insecticides for codling moth control, 2005-2007.

DISCUSSION

The responses to the two neonicotinoid insecticides used in the large-block study confirms previous work done on small plots (Beers *et al.* 2005). Mite populations in the acetamiprid treatments averaged 2.3, 2.2 and 3.0× higher than the standard organophosphate treatment during 2005-2007, respectively. Mite populations in the thiacloprid treatments averaged 1.3, 3.4 and 2.2× higher than the standard. In addition to the neonicotinoids, this study provides evidence that novaluron also causes disruption of integrated mite management, although this trend was not apparent in small-plot trials (J. Brunner, personal communication). Mite populations in the novaluron treatments were 2.1, 7.6, and 2.7× higher than the standard treatment in the three years of the study.

Although widely observed, the mecha-

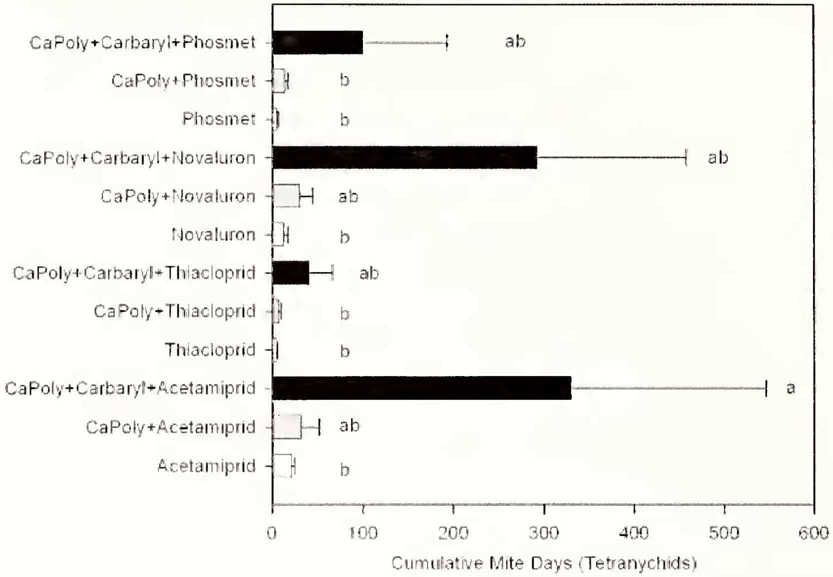

Figure 2. Additive effect of thinning materials and codling moth insecticides on seasonal

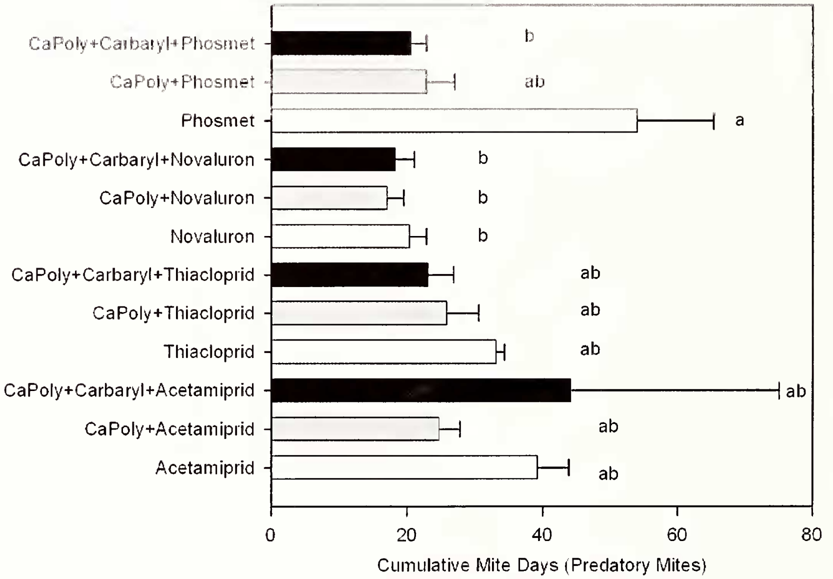

Figure 3. Additive effect of thinning materials and codling moth insecticides on seasonal predatory mite populations. F=2.05, P=0.054, df=11, 47. Data transformed log(x+0.5) prior to

nism for the neonicotinoid effect has never been clearly established. Hormoligosis is thought to play a role in stimulating pest reproduction (James and Price 2002), but other studies have found no hormoligosis effect (Ako *et al.* 2004, Ako *et al.* 2006). Conversely, neonicotinoids have also been found to stimulate reproduction in beneficial arthropods (James 1997). Repellency (James 1997) and suppression of functional

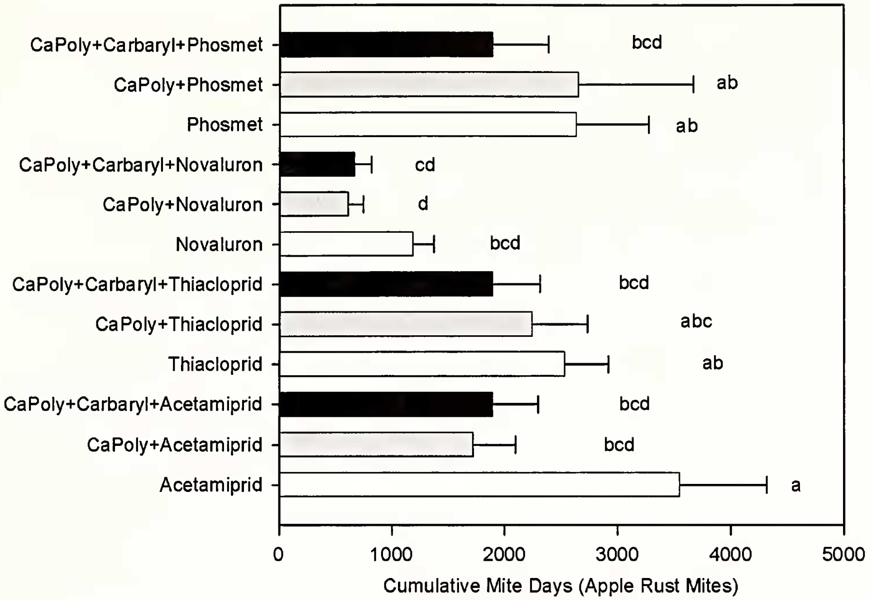

Figure 4. Additive effect of thinning materials and codling moth insecticides on seasonal apple rust mite populations. $F = 3.03$, $P = 0.0067$, df = 11, 47.

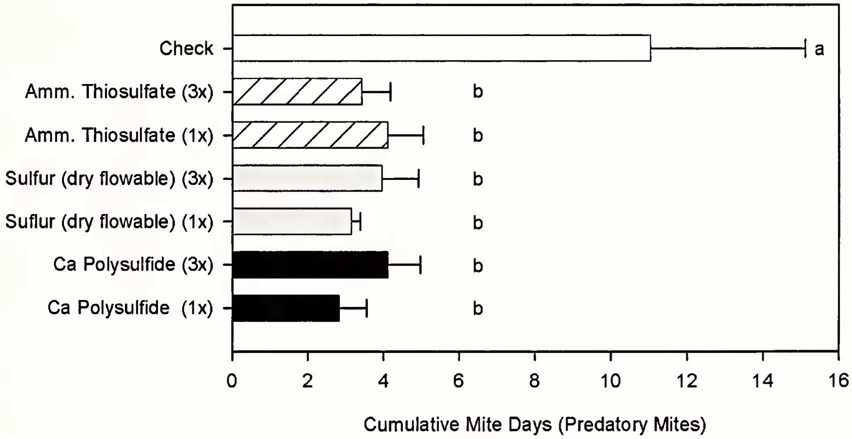

Figure 5. Effect of sulfur-containing products on predatory mites. $F = 2.68$, P=0.0.049, df = 6, 27.

response (Poletti *et al.* 2007) may also play a role in the disruption of biological control.

It is evident from previous studies (Beers *et al.* 2005) that while neonicotinoids can cause mite outbreaks, they would not do so in every case. This makes the role of other disruptive materials more important on a relative scale. In an organophosphate-based pest management program, calcium polysulfide and carbaryl had been used with few apparent deleterious effects; under this program, only about 7% of Washington's apple orchards were treated with acaricides (NASS 1992). The low mite levels documented by the survey are likely typical of acaricide use from the early 1970s, when integrated mite control was first established, until the early 2000s when shifts in codling moth insecticides began. However, there has been a substantial increase in the percentage of Washington apple acreage treated with sulfur fungicides (7.8×) and calcium polysulfide (11×) since

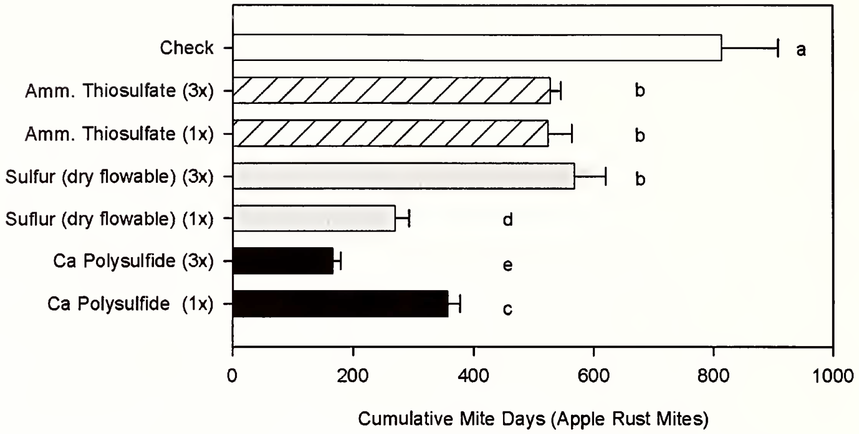

Figure 6. Effect of sulfur-containing products on apple rust mite. $F = 22.3$, $P = <0.0001$, df = 6, 27.

1991 (NASS 1992, 2006). These compounds, which are typically applied early in the season, may predispose the orchard to later disruption by codling moth insecticides.

The toxic effect of carbaryl and sulfur-containing products on mites is well known (McMurtry *et al.* 1970). In the case of carbaryl, moderate levels of resistance in *G. occidentalis* (Babcock and Tanigoshi 1988) may have mitigated the disruptive effect to some extent. Sulfur products have a long history of disruption of integrated mite control, and although resistance in *G. occidentalis* populations had been found in California vineyards, this had apparently not occurred in Washington orchards (Hoy and Standow 1982). Thus it is reasonable to expect that increased use of these materials could contribute to mite outbreaks.

The organophosphate–based programs of the past few decades have provided one of the most stable periods in integrated mite control in Washington orchards. The insecticides that replaced the organophosphates were initially thought to be more selective, but a number have shown nontarget effects on beneficial arthropods. Because of this destabilization, acaricide use has increased in recent years (NASS 1992, 2006), leading to increased production costs and increasing the probability for resistance development in pest mite species. It could be argued that because of widespread resistance to organophosphates in populations of both pests and natural enemies, that many of the organophosphates are now fairly selective from a pest management perspective. While human and environmental health concerns outweigh pest management issues, it will require further study and manipulation to re-establish the highly successful integrated mite control program as the primary means of mite control in Washington apple orchards.

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